Lat 39.69024 Lon -120.54722

Forest Health Protection
Pacific Southwest Region
Northeastern California Shared Service Area

Date: July 30, 2018
File Code: 3420

To: District Ranger, Beckwourth Ranger District, Plumas National Forest

Subject: Evaluation of stand conditions with respect to forest insects and disease within the Haskell project, Plumas National Forest (FHP Report NE18-06)

At the request of Paul Czeszynski, Silviculturist, Beckwourth Ranger District, Danny Cluck, Forest Health Protection (FHP) Entomologist, visited the Haskell project on June 29, 2018. The objective of this visit was to evaluate current stand conditions, determine the impacts of forest insects and diseases on management objectives and discuss proposed alternatives. Recommendations provided in this report will assist in the formulation of silvicultural prescriptions aimed at reducing stand density and increasing resiliency to disturbance agents such as fire, insects and diseases.

Key Findings

- High stand density is putting many stands at risk to high levels of bark beetle-caused tree mortality during periods of drought. Many of these same stands are also at risk to high severity wildfire (Figure 1).
- Mixed conifer stands in general have become overstocked with a high percentage of white fir that is inhibiting the regeneration of shade intolerant pine species.
- High levels of recent white fir mortality associated with drought, disease and fir engraver beetle are common throughout the project area.
- White pine blister rust is infecting sugar and western white pine, increasing the susceptibility of mature trees to bark beetle attack and negatively impacting regeneration.
- Several red fir stands are declining due to a combination of root disease, dwarf mistletoe and Cytospora canker.
- Thinning and prescribed fire are highly recommended throughout the project area to reduce tree density and reduce surface and ladder fuels. Specific recommendations are provided in this evaluation.

Danny Cluck
Forest Entomologist
530-252-6431
dcluck@fs.fed.us

Bill Woodruff
Plant Pathologist
530-252-6880
wwoodruff@fs.fed.us

Description of the project area

The Haskell project is located 8 miles southeast of Graeagle, CA (39.690241N and 120.547219E). The elevation ranges from 4,800 – 8,100 feet with annual precipitation ranging between 35 and 85 inches. Sierra Nevada mixed conifer dominates the middle elevations with ponderosa pine (*Pinus ponderosa*), Jeffrey pine (*Pinus jeffreyi*), Douglas-fir (*Psuedotsuga menziesii*), sugar pine (*Pinus lambertiana*), incense cedar (*Calocedrus decurrens*), white fir (*Abies concolor*), and red fir (*Abies magnifica*). Higher elevations contain mostly red fir, western white pine (*Pinus monticola*) and Jeffrey pine. The lower elevation eastern end of the project area is mostly dominated by ponderosa and Jeffrey pine.

Management objectives

The Haskell project proposes to reduce the risk of insect and disease-caused tree mortality through mechanical thinning. Fuels reduction and maintenance would also be accomplished with mastication and prescribed burning. White fir will be removed in favor of retaining other tree species in mixed conifer stands. Residual stands will be more open, increasing the amount of available soil moisture and sunlight for individual trees. Treatment in red fir stands will focus on creating openings for successful tree regeneration by removing pockets of diseased overstory trees.

Figure 1. Dense stand conditions within a mixed conifer area of the Haskell project

Forest insect and disease conditions

Agents observed:

High levels of white fir mortality caused by the fir engraver beetle (*Scolytus ventralis*).

Evidence of older fir engraver attacks on white fir throughout the area (snags and downed logs). Most of this older mortality likely occurred as a result of the 1987 – 1992 drought.

Heterobasidion root disease, caused by *Heterobasidion occidentale,* in white fir and red fir at various levels throughout the project area.

True fir dwarf mistletoe (*Arceuthobium abietinum* f. sp. *magnificae*) and Cytospora canker (*Cytospora abietis*) in red fir causing branch flagging and crown dieback. True fir dwarf mistletoe was also found in white fir in some locations.

White pine blister rust (*Cronartium ribicola*) in sugar pine and western white pine (Figure 2). Infections in western white pine are especially severe causing top-kill and whole tree mortality of all size classes.

Figure 2. Limb die-back in blister rust infected western white pine

Mountain pine beetle (*Dendroctonus ponderosae*)-caused mortality of sugar pine and western white pine, often associated with white pine blister rust.

Large areas with elevated white and red fir mortality were also mapped in 2017 during the annual tree mortality aerial detection survey (Figures 3 and 4).

<u>Stand conditions and mortality related to recent and future climate trends</u>

Most of the stands within the Haskell project appear to be at or above "normal" stocking levels and many have exhibited elevated levels of tree mortality caused by bark beetles during and after periods of drought (Figure 5 and Table 1). This mortality combined with high stand density has resulted in heavy fuel loading in some areas and a corresponding increase in potential fire behavior.

Tree mortality attributable to insects and/or pathogens is elevated throughout the project area and has increased dramatically over the last year (Table 1). Elevated levels of tree mortality in this area, as well as in the rest of the Sierra Nevada range, are strongly associated with periods of below normal precipitation and high stand density. Successive dry years can exacerbate unhealthy stand conditions, such as those that exist within the Haskell project; resulting in higher levels of bark beetle-caused tree mortality. The Palmer Hydrologic Drought Index is also included in Table 1 to show the relationship between drought and tree mortality. The high number of dead trees mapped in 2017 were mostly white fir that were attacked by fir engraver beetle in 2016 before the wet winter of 2016/2017.

Figure 3. Areas with aerially mapped tree mortality in 2017 within the Haskell project.

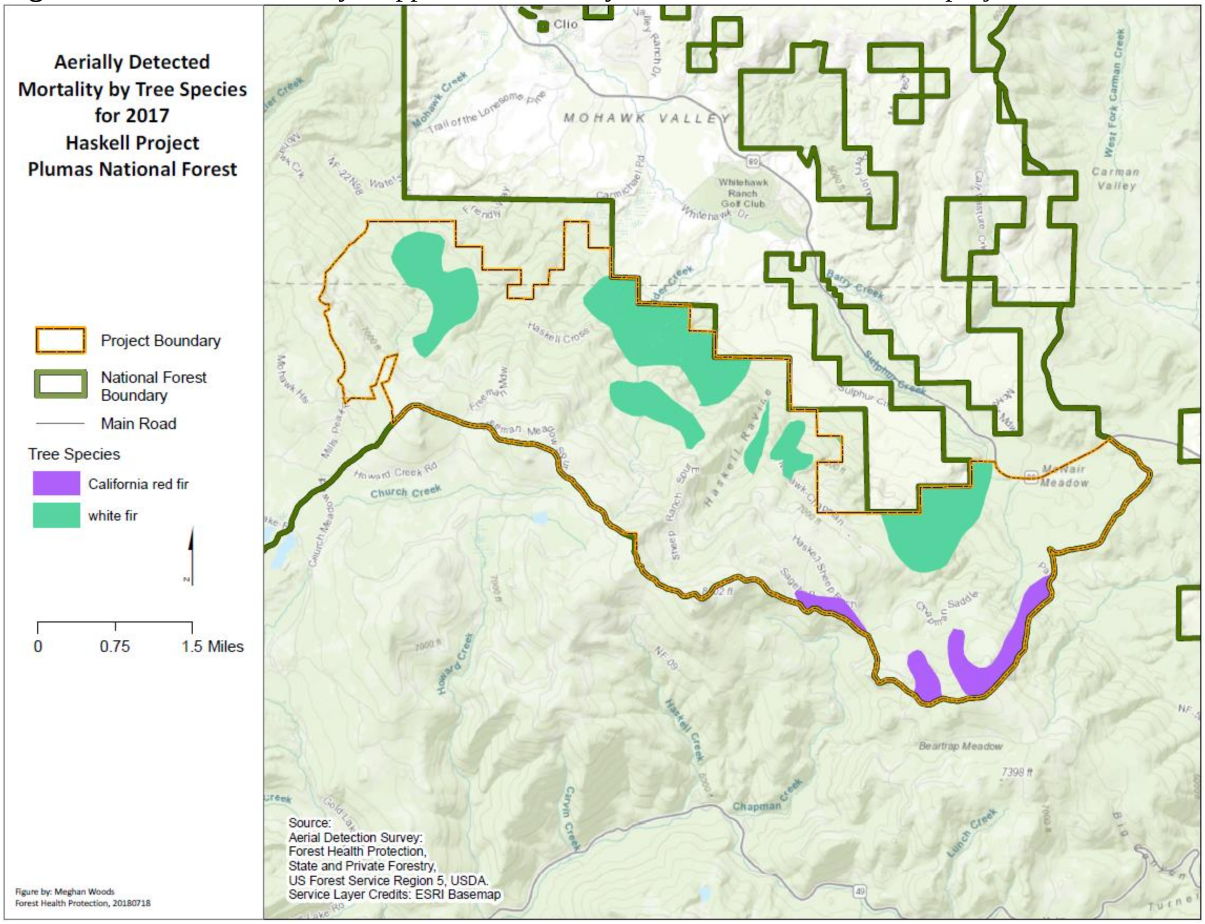


Figure 4. Scattered white fir mortality within the Haskell project in 2017 (Photo credit: 2017 ADS)

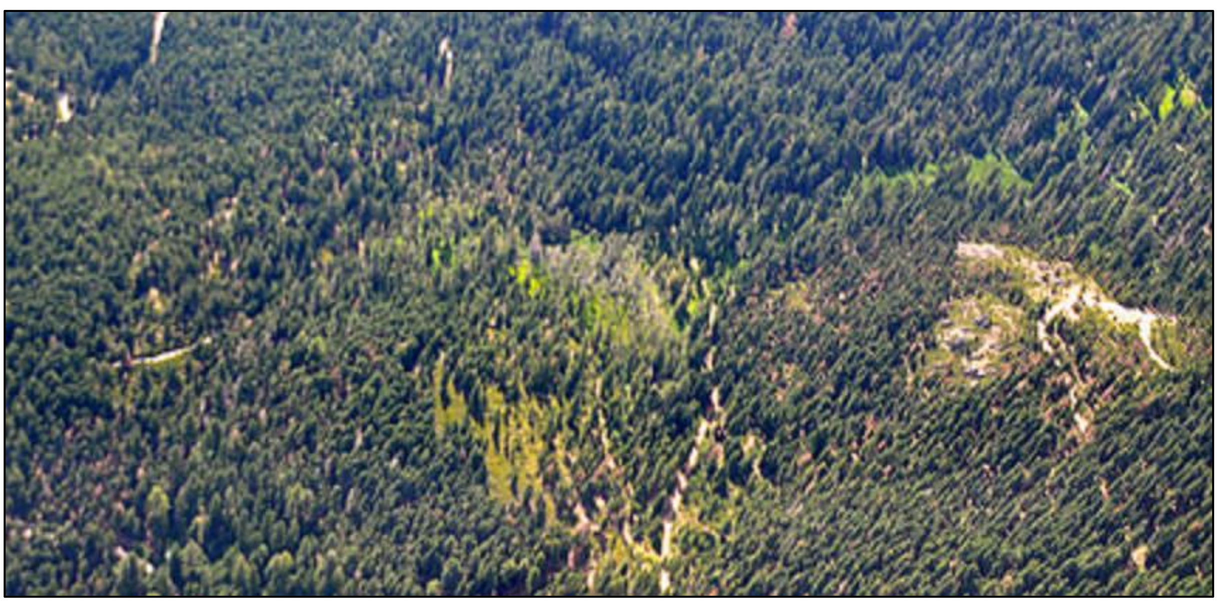


Figure 5 also depicts many areas where no mortality was mapped over the past 10 years. This is not uncommon for Sierra mixed conifer stands that typically receive > 40” of precipitation per year. However, many stands do exist within this “mortality free” zone that are at a high risk to bark beetle and pathogen-caused tree mortality due to overstocked conditions and could experience unacceptable levels of tree mortality during prolonged and/or severe drought. For example, the recent exceptional drought in the south Sierra Nevada range resulted in high levels of mortality in mixed conifer stands similar to the Haskell project stands.

At lower elevations, dense stand conditions and an abundance of white fir appear to have greatly reduced the amount of regeneration of shade intolerant species. The distribution and species composition of old growth trees and stumps remaining within these portions of the project area (mostly IC, SP, DF, PP, JP) suggests that stands were more open in the past, maintained by frequent low severity fire, with fewer white fir.

Figure 5. Areas of tree mortality and dead trees per acre between 2008 and 2017 within the Haskell project

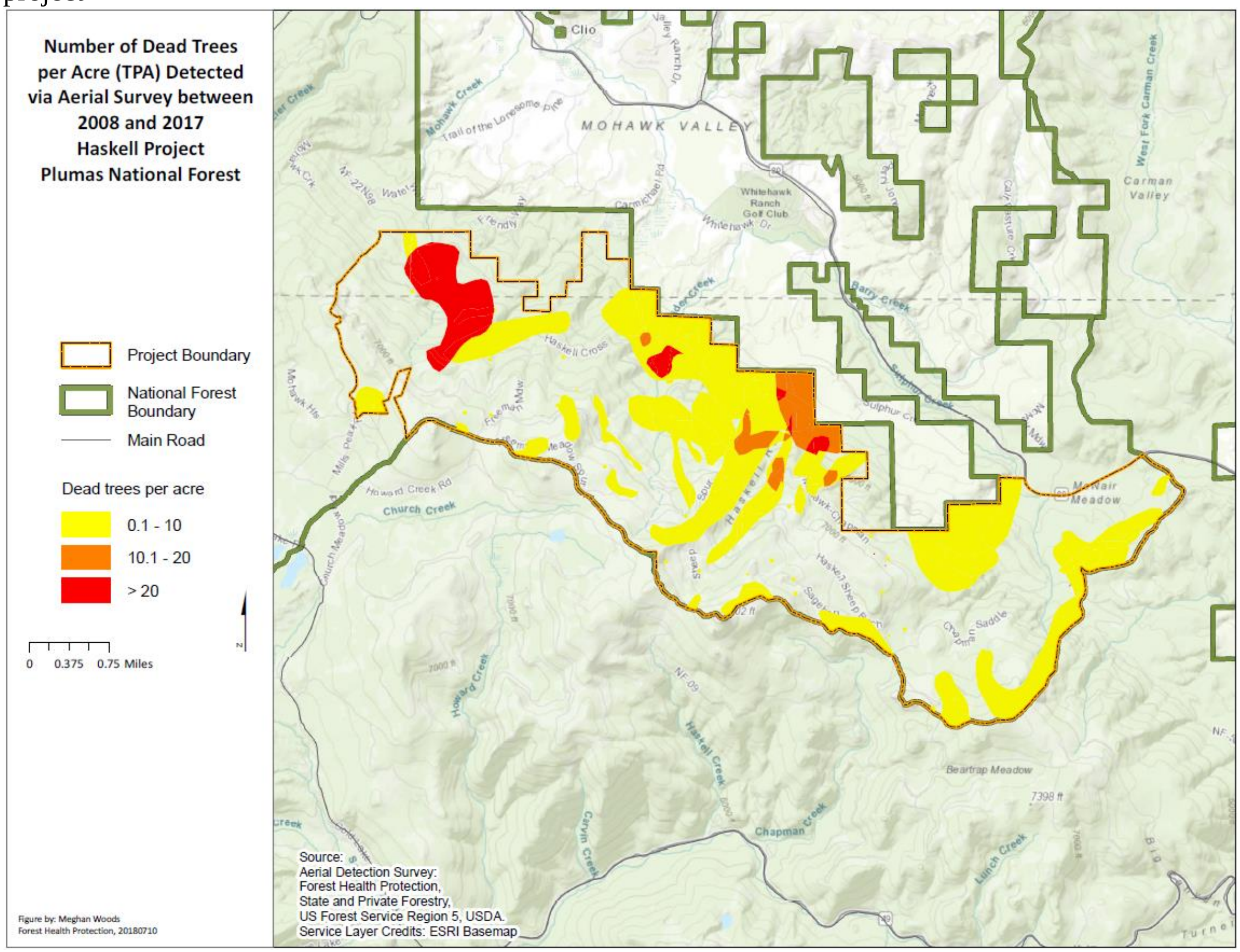


Table 1. Acres with mortality, estimated dead trees per acre and estimated total # of dead trees from R5 Aerial Detection Surveys and Palmer Hydrologic Drought Index (PHDI) (average of CA Divisions 2 and 3[1]) by water year (Oct-Sept) within the Haskell project area.

Year	Acres	Dead Trees/Acre	Total # of Dead Trees	PHDI[2]
2017	1,897	8.1	15,271	3.00
2016	471	2.1	1,008	-1.32
2015	116	2.3	261	-3.34
2014	54	1.9	105	-3.56
2013	24	2.4	58	-2.16
2012	4	2.0	8	-0.59
2011	211	13.0	2,755	2.78
2010	938	4.4	4,129	-0.14
2009	212	2.3	496	-2.98
2008	2	5.5	11	-3.16

[1] California Divisions 2 and 3 encompass most of northeastern California.
[2] PHDI values ranging from -2.00 to -2.99 are considered moderate drought conditions. Severe drought conditions range from -3.00 to -3.99 and extreme drought conditions are below -4.00.

Predicted climate change is likely to impact trees growing in the Haskell area over the next 100 years. Although no Plumas National Forest specific climate change models are available at this time, there is a general consensus among California models that summers will be drier than they are currently. This prediction is based on the forecasted rise in mean minimum and maximum temperatures and remains consistent regardless of future levels of annual precipitation (K. Merriam and H. Safford, *A summary of current trends and probable future trends in climate and climate-driven processes in the Sierra Cascade Province, including the Plumas, Modoc, and Lassen National Forests*. The risk of bark beetle-caused tree mortality will likely increase for all conifer species under this scenario, especially drought intolerant white fir and decadent red fir stands with high levels of disease. Improving the resilience of stands to future disturbance events through density, size class and species composition management will be critical to maintaining a healthy forested landscape. Anticipating future drought events and reducing tree density to levels that are more resilient and sustainable should reduce the risk of unacceptable levels of tree mortality within the Haskell project area.

Considerations for thinning treatments

Most of the thinning treatments proposed by the District should reduce stand density to a level that significantly lowers the risk of bark beetle caused mortality. In most cases, thinning to a relative density of 25 - 40% (relative to the maximum Stand Density Index, or SDI) for a specific conifer species or for a weighted composition of conifer species will effectively reduce competition for limited water and nutrients and reduce the susceptibility to future bark beetle-caused tree mortality for many years. The District should consider an SDI max of 450 for drier pine-dominated mixed conifer (Long and Shaw 2005) and SDI max 550 (Long and Shaw 2012) for fir-dominated mixed conifer on more mesic north facing aspects. The District should also consider reducing the SDI in ponderosa/Jeffrey pine dominated stands to below 230. SDI 230 is the defined threshold for the zone of imminent bark beetle caused mortality (Oliver 1995). Thinning stands to this level will reduce the risk of additional bark beetle-caused mortality by reducing tree competition for limited water and nutrients. Red fir stands should be managed to

provide openings for healthy red fir regeneration, reduce disease levels and provide opportunities for western white pine regeneration, including the planting of rust-resistant seedlings.

When planning thinning treatments, it should be recognized that the target stand density is an average to be applied across the landscape and some variability may be desired. Individual high value trees, such as mature pines, should benefit by having the stocking around them reduced to lower levels. Allowing for denser tree spacing and pockets of higher canopy cover may be desirable around potential wildlife trees, such as forked and/or broken-topped trees, or on more mesic north-facing slopes. Incorporating the concepts of GTR 220 will address many of these issues and be consistent with Regional ecosystem restoration goals. Many of these methods are also consistent with past FHP recommendations for thinning in mixed conifer stands and their use is supported for the Haskell project.

The presence of Heterobasidion root disease in true fir, especially white fir, should be considered when developing silvicultural prescriptions. Root diseased true fir are at a higher risk for fir engraver attacks than uninfected trees during droughts. Leaving high numbers of root diseased trees will likely lead to higher levels of mortality over the long-term, reducing large tree canopy cover and increasing fuels. Leaving these trees will also reduce opportunities for successful regeneration of shade intolerant species that are not susceptible hosts to *H. occidentale*.

The best option for managing *H. occidentale* in white fir is to reduce its overall abundance in the stand and remove severely infected trees. Various sized openings can be created in the stand to facilitate planting of non-hosts such as ponderosa, Jeffrey and sugar pine. Placing these openings on known or suspected root disease pockets will enhance the effectiveness of this strategy for reducing overall infection levels. In addition, greatly reducing white fir stocking in stands that have a non-host overstory component will allow for natural non-host regeneration and create a more resilient species composition over time.

In red fir stands that are heavily infected with dwarf mistletoe and Cytospora (and potentially *H. occidentale*), thinning and/or prescribed fire treatments should emphasize a reduction in the number of heavily infected trees (i.e. dwarf mistletoe and Cytospora abundant throughout the crown), an increase in species diversity and the creation of openings that facilitate the establishment of disease free regeneration. Dwarf mistletoe disperses most effectively from overstory trees to smaller trees of the same species. Thus, spread tends to be most efficient in multi-storied stands of the same host tree species. In areas where young regeneration is already established but not yet significantly infected with dwarf mistletoe, moderate to heavily infected overstory trees can be removed to reduce the number of additional infections. In infected areas without understory trees, openings can be created to encourage healthy regeneration. These openings can vary in size but should be large enough to provide a significant buffer from infected overstory trees that can spread dwarf mistletoe seed horizontally up to 60 feet or even further during strong winds. A rule of thumb is that the seeds can travel a horizontal distance equal to the height of the highest plant in an infected tree. Openings created in suspected root disease pockets can be replanted with non-hosts such as western white pine (*Pinus monticola*) if deemed appropriate for the site. Otherwise, providing new growing space for red fir regeneration will reduce the overall impact of root disease within the stand.

It is recommended that a registered borate compound be applied to all freshly cut conifer stumps >14” in diameter to reduce the chance of creating new infection centers of *Heterobasidion irregulare* and *H. occidentale* formerly referred to as P-type and S-type annosus root disease,

through harvest activity. An exception to this recommendation would be to not treat white fir stumps in mixed conifer stands or more pure white fir stands if there is already a high level of Heterobasidion root disease present as treating white fir stumps in heavily infected stands is ineffective.

Sugar and western white pine should be retained as much as possible during any thinning operation in order to preserve genetic diversity, especially white pine blister rust (*Cronartium ribicola*) resistant individuals. An exception to this would be thinning suppressed trees within pure sugar or western white pine groups to reduce inter-tree competition. White pine blister rust, a non-native pathogen, has continued to weaken and kill this species over most of its range since its introduction into the Pacific Northwest in 1910. Identification and protection of local rust resistant trees for seed collection, if not already occurring, will aid in the future planting of rust resistant seedlings. Planting selected openings created through thinning operations with rust resistant stock would help insure this species persists in the area.

Forest Health Protection recently developed a treatment priority map for Region 5 to help land managers prioritize thinning treatments at the landscape level. This map depicts forested areas on National Forest System lands that are the most susceptible to drought and bark beetle-caused tree mortality based on forest type and stand density. These areas also meet the criteria of existing on slopes <=35% and being outside of wilderness areas, wild and scenic river corridors, designated roadless areas and California spotted owl protected activity centers. Additional criteria include not having burned at moderate to high severity since 1998 and not having been thinned since 2005. In addition to being overly dense, these areas have a history of tree mortality during drought resulting in heavy fuel loads and higher risk of stand replacing wildfire. Highest priority areas consist of high density pine stands, pine-dominated mixed conifer stands and fir-dominated mixed conifer and white fir stands growing on historically pine dominated sites. Second priority areas consist of high density fir-dominated mixed conifer and white fir stand on wetter sites. All mapped stands are California Wildlife Habitat Relationship size class 4, 5 and 6.

Figure 6 shows treatment priority areas within the Haskell project boundary. This mapping effort utilized remotely sensed data to create treatment priority layers for large scale planning and may not be accurate at the stand level. The forest should still use stand records and stand exam data to identify treatment areas and develop silvicultural prescriptions. An ALL LANDS version of the map was also created that includes wilderness areas, wild and scenic river corridors, designated roadless areas and California spotted owl protected activity centers to evaluate stand conditions in these protected areas. It also includes slopes >35% and all land ownerships (Figure 7).

<u>Considerations for Rx fire</u>

If prescribed fire is used as a follow-up treatment to stand thinning, it may result in unacceptable levels of tree mortality; depending on management objectives. This mortality most often occurs as a direct result of cambium or crown injury to individual trees during the fire. Mature ponderosa, Jeffrey and especially sugar pines are susceptible to lethal basal cambium damage during prescribed burns from the heat that develops in the deep duff and litter that accumulates at their bases. These duff mounds typically burn at a slow rate with lethal temperatures, causing severe injury to the cambium which girdles the trees. To protect individual high-value large diameter pine from lethal cambium damage, raking the duff away from the bases of these trees before burning (within 24” of the bole and down to mineral soil) is recommended.

Potential for funding thought the Western Bark Beetle Program

Forest Health Protection may be able to assist with funding, including NEPA activities, for thinning and removing green material from overstocked areas within the Haskell project area. Thinning treatments that reduce stand density sufficient to lower the risk to bark beetle-caused mortality would meet the minimum requirements for Western Bark Beetle Program funding and would be supported by this evaluation. If you are interested in this competitive funding please contact me for assistance in developing and submitting a proposal.

If you have any questions regarding this report and/or need additional information please contact Danny Cluck at 530-252-6431.

/s/ Danny Cluck

Daniel R. Cluck
Forest Entomologist
NE CA Shared Services Area

cc: Paul Czezsynski, Silviculturist, Beckwourth RD
Ryan Tompkins, Forest Vegetation Officer, Plumas SO
Forest Health Protection, Regional Office

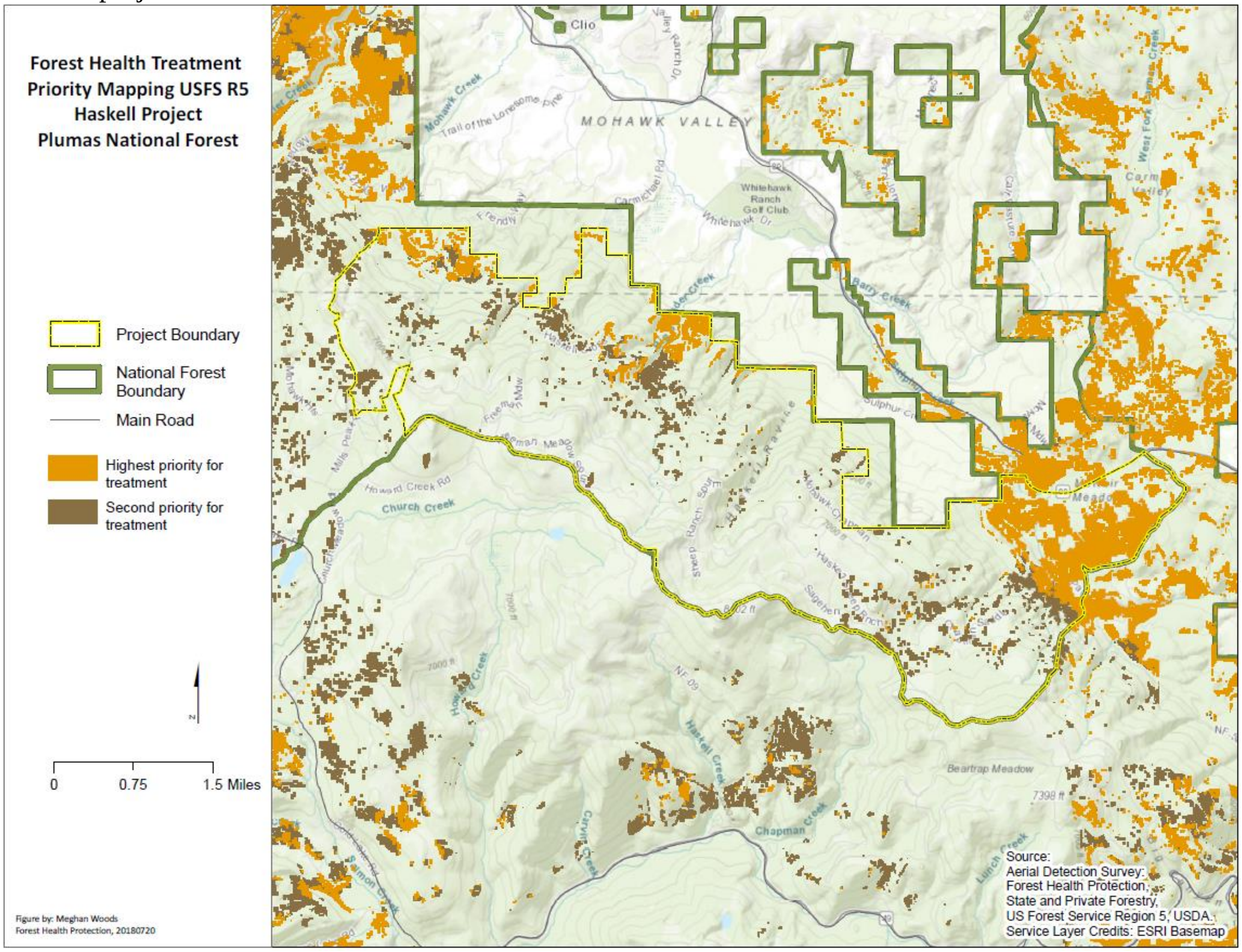
References

Long, J.N., and J.D. Shaw. 2005. A density management diagram for even-aged ponderosa pine stands. *West. J. Appl. For.* 20:205–215.

Long, J.N., and J.D. Shaw. 2012. A density management diagram for even-aged Sierra Nevada mixed-conifer stands. *West. J. Appl. For.* 27(4):187-195.

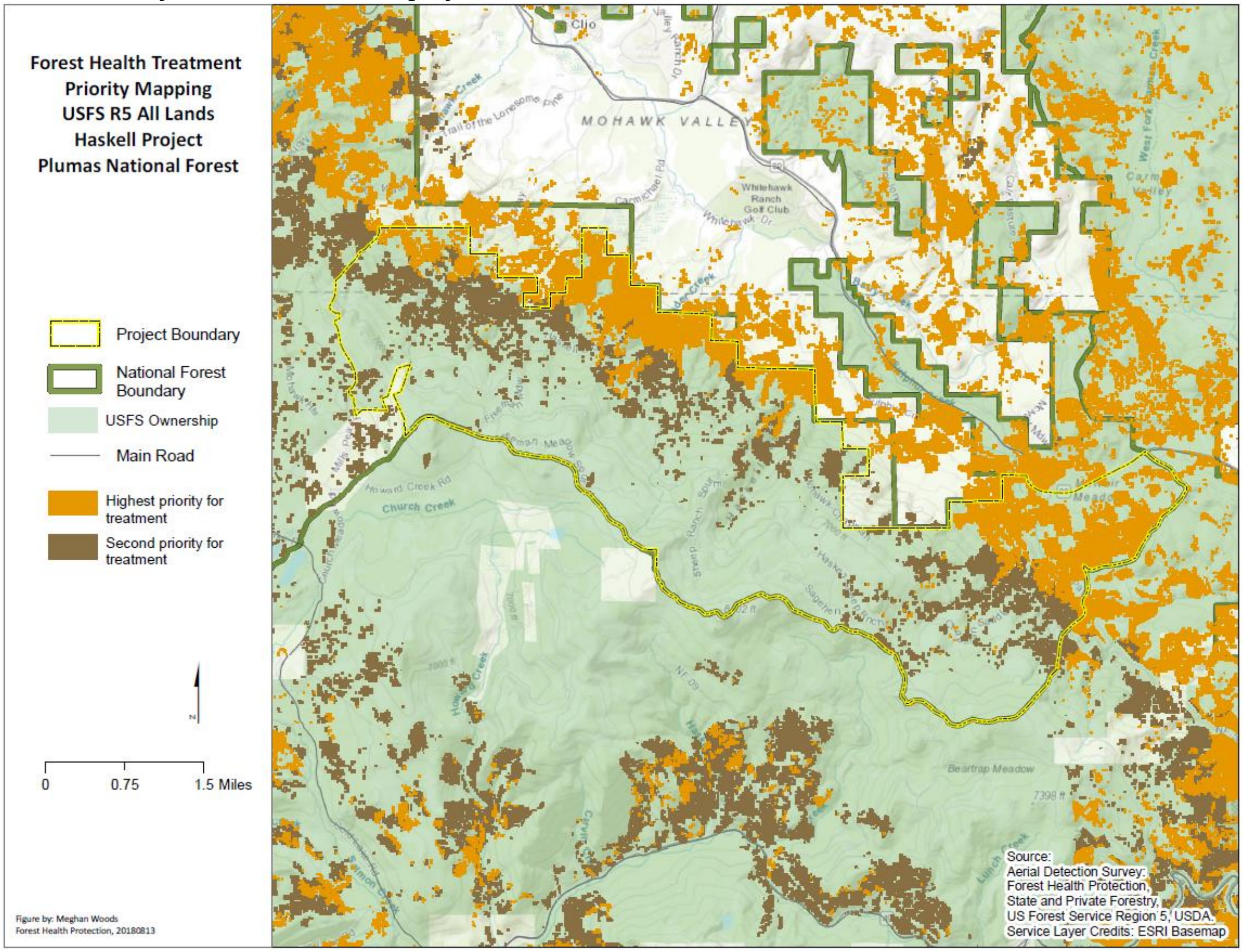
Oliver, W.W., 1995. Is self-thinning in ponderosa pine ruled by Dendroctonus bark beetles? In: Proceedings of the 1995 National Silviculture, Workshop, GTR-RM-267. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, C.O., pp., 213–218.

Figure 6. Treatment Priority Areas* at risk to bark beetle-caused mortality within and adjacent to the Haskell project area.



*Highest priority treatment areas include overly dense stands (>60% of maximum stand density index) of pine and pine-dominated mixed conifer stands as well as fir-dominated mixed conifer and white fir stands growing on historically pine-dominated sites. Second priority treatment areas include overly dense stands of fir-dominated mixed conifer and white fir. Mapped areas only include CWHR size class 4, 5 and 6 stands. Wilderness areas, inventoried roadless areas, wild and scenic areas, spotted owl protected activity centers, moderate to high severity burned areas since 1998, areas thinned since 2005, areas with >35% slope and all non-National Forest System lands were excluded from this analysis. Red fir stands, which make up a large portion of the project area, were also not included in this analysis.

Figure 7. Treatment Priority Areas (ALL LANDS version)* at risk to bark beetle-caused mortality within and adjacent to the Haskell project area.



*Highest priority treatment areas for ALL LANDS version include overly dense stands (>60% of maximum stand density index) of pine and pine-dominated mixed conifer stands as well as fir-dominated mixed conifer and white fir stands growing on historically pine-dominated sites. Second priority treatment areas include overly dense stands of fir-dominated mixed conifer and white fir. Mapped areas only include CWHR size class 4, 5 and 6 stands. Moderate to high severity burned areas since 1998, areas thinned or that experienced stand replacing disturbance such as clear cuts or bark beetle-caused tree mortality since 2005 were excluded from this analysis. Red fir stands, which make up a large portion of the project area, were also not included in this analysis.

Insect and Disease Information

Fir Engraver

The fir engraver attacks red and white fir in California. Fir engraver adults and developing broods kill true firs by mining the cambium, phloem, and outer sapwood of the bole, thereby girdling the tree. Trees greater that 4" in diameter are attacked and often killed in a single season. Many trees, weakened through successive attacks, die slowly over a period of years. Others may survive attack as evidenced by old spike-topped fir and trees with individual branch mortality. Although many other species of bark beetles cannot develop successful broods without killing the tree, the fir engraver beetle is able to attack and establish broods when only a portion of the cambium area has been killed.

Evidence of Attack

Fir engravers bore entrance holes along the main stem, usually in areas that are > 4" in diameter. Reddish-brown or white boring dust may be seen along the trunk in bark crevices and in spider webs. Some pitch streamers may be indicative of fir engraver attacks; however, true firs are known to stream pitch for various reasons and there is not clear evidence that pitch streamers indicate subsequent tree mortality or successful attack. Resin canals and pockets in the cortex of the bark are part of the trees defense mechanism. Beetle galleries that contact these structures almost always fail to produce larval galleries as the adults invariably abandon the attack. Pitch tubes, often formed when bark beetles attack pine, are not produced on firs.

Adults excavate horizontal galleries that engrave the sapwood; the larval galleries extend at right angles along the grain. Attacks in the crown may girdle branches resulting in individual branch mortality or "flagging". Numerous attacks over part or the entire bole may kill the upper portion of the crown or the entire tree. A healthy tree can recover if sufficient areas of cambium remain and top-killed trees can produce new leaders. The fir engraver is frequently associated with the roundheaded fir borer and the fir flatheaded borer.

Life Stages and Development

In the summer, adults emerge and attack new host trees. The female enters the tree first followed by the male. Eggs are laid in niches on either side of the gallery. Adult beetles carry the brown staining fungi, *Trichosporium symbioticum*, into the tree that causes a yellowish-brown discoloration around the gallery. The larvae mine straight up and down, perpendicular to the egg gallery. Winter is commonly spent in the larval stage, with pupation occurring in early spring. In most locations, the fir engraver completes its life cycle in 1 year, however at higher elevations 2 years may be required.

Conditions Affecting Outbreaks

Fir engravers bore into any member of the host species on which they land but establish successful galleries only in those that have little or no resistance to attack. Populations of less aggressive species like fir engraver are likely to wax and wane in direct relationship to the stresses of their hosts. Drought conditions often result in widespread fir mortality; however, attempting to determine when outbreaks will occur is difficult. Lowered resistance of trees appears to be a contributing factor. Overstocking and the increased presence of fir on sites that were once occupied by pine species may also contribute to higher than normal levels of fir mortality. Several insect predators, parasites and woodpeckers are commonly associated with the fir engraver and may help in control of populations at endemic levels.

Mountain pine beetle

The mountain pine beetle, *Dendroctonus ponderosae*, attacks the bole of ponderosa, lodgepole, sugar and western white pines larger than about 8 inches dbh. Extensive infestations have occurred in mature lodgepole pine forests. Group killing often occurs in mature forests and young overstocked stands of ponderosa, sugar and western white pines.

Evidence of Attack

The first sign of beetle-caused mortality is generally discolored foliage. The mountain pine beetle begins attacking most pine species on the lower 15 feet of the bole. Examination of infested trees usually reveals the presence of pitch tubes. Pitch tubes on successfully infested trees are pink to dark red masses of resin mixed with boring dust. Creamy, white pitch tubes indicate that the tree was able to "pitch out" the beetle and the attack was not successful. In addition to pitch tubes, successfully infested trees will have dry boring dust in the bark crevices and around the base of the tree. Attacking beetles carry the spores of blue-staining fungi which develop and spread throughout the sapwood interrupting the flow of water to the crown. The fungi also reduces the flow of pitch in the tree, thus aiding the beetles in overcoming the tree. The combined action of both beetles and fungi causes the needles to discolor and the tree to die.

Life Stages and Development

The beetle develops through four stages: egg, larva, pupa and adult. The life cycle of the mountain pine beetle varies considerably over its range. One generation per year is typical, with attacks occurring from late June through August. Two generations per year may develop in low elevation sugar pine. Females making their first attacks release aggregating pheromones. These pheromones attract males and other females until a mass attack overcomes the tree. The adults bore long, vertical, egg galleries and lay eggs in niches along the sides of the gallery. The larvae feed in mines perpendicular to the main gallery and construct small pupal cells at the end of these mines where they pupate and transform into adults.

Conditions Affecting Outbreaks

The food supply regulates populations of the beetle. In lodgepole pine, it appears that the beetles select larger trees with thick phloem, however the relationship between beetle populations and phloem thickness in other hosts has not been established. A copious pitch flow from the pines can prevent successful attack. The number of beetles, the characteristics of the tree, and the weather affect the tree's ability to produce enough resin to resist attack. Other factors affecting the abundance of the mountain pine beetle include nematodes, woodpeckers, and predaceous and parasitic insects. As stand susceptibility to the beetle increases because of age, overstocking, diseases or drought, the effectiveness of natural control decreases and pine mortality increases.

Heterobasidion Root Disease

Heterobasidion spp. is a fungus that attacks a wide variety of woody plants. All western conifer species are susceptible. Madrone (*Arbutus menziesii*), and a few brush species (*Arctostaphylos spp.* and *Artemisia tridentata*) are occasional hosts. Other hardwood species are apparently not infected. The disease has been reported on all National Forests in California, with incidence particularly high on true fir in northern California, in the eastside pine type forests, and in southern California recreation areas.

Heterobasidion root disease is one of the most important conifer diseases in Region 5. Current estimates are that the disease infests about 2 million acres of commercial forestland in California, resulting in an annual volume loss of 19 million cubic feet. Other potential impacts of the disease include: increased susceptibility of infected trees to attack by bark beetles, mortality of infected trees

presently on the site, the loss of the site for future production, and depletion of vegetative cover and increased probability of tree failure and hazard in recreation areas.

During periods favorable to the fungus, fruiting bodies (conks) form in decayed stumps, under the bark of dead trees, or under the duff at the root collar. New infection centers are initiated when airborne spores produced by the conks land and grow on freshly cut stump surfaces. Infection in true fir may also occur through fire and mechanical wounds, or occasionally, through roots of stumps in the absence of surface colonization. From the infected stump surface, the fungus grows down into the roots and then spreads via root-to-root contact to adjacent live trees, resulting in the formation of large disease centers. These infection centers may continue to enlarge until they reach barriers, such as openings in the stand or groups of resistant plants. In pines, the fungus grows through root cambial tissue to the root crown where it girdles and kills the tree. In true fir and other non-resinous species, the fungus sometimes kills trees, but more frequently is confined to the heartwood and inner sapwood of the larger roots. It then eventually extends into the heartwood of the lower trunk and causes chronic decay and growth loss.

Heterobasidion root disease in western North America is caused by two species: *Heterobasidion occidentale* (also called the 'S' type) and *H. irregulare* (also called the 'P' type). These two species of *Heterobasidion* have major differences in host specificity. *H. irregulare* (‘P’ type) is pathogenic on ponderosa pine, Jeffrey pine, sugar pine, Coulter pine, incense cedar, western juniper, pinyon, and manzanita. *H. occidentale* (‘S’ type) is pathogenic on true fir, spruce and giant sequoia. This host specificity is not apparent in isolates from stumps; with *H. occidentale* being recovered from both pine and true fir stumps. These data suggest that infection of host trees is specific, but saprophytic colonization of stumps is not. The fungus may survive in infected roots or stumps for many years. Young conifers established near these stumps often die shortly after their roots contact infected roots in the soil.

Dwarf mistletoe

Dwarf mistletoes (*Arceuthobium* spp.) are parasitic, flowering plants that can only survive on living conifers in the Pinaceae. They obtain most of their nutrients and all of their water and minerals from their hosts.

Dwarf mistletoes spread by means of seed. In the fall the fruit ripen and fall from the aerial shoots. The seeds are forcibly discharged. The seed is covered with a sticky substance and adheres to whatever it contacts. When a seed lands in a host tree crown, it usually sticks to a needle or twig, where it remains throughout the winter. The following spring the seed germinates and penetrates the twig at the base of the needle. For the next 2-4 years, the parasite grows within the host tissues, developing a root-like system within the inner bark and outer sapwood, and causing the twig or branch to swell. Aerial shoots then develop and bear seed in another 2-4 years.

Dispersal of dwarf mistletoe seeds is limited to the distance the seeds travel after being discharged. From overstory to understory, this is usually 20 to 60 feet, but wind may carry them as far as 100 feet from the source. A rule of thumb is that the seeds can travel a horizontal distance equal to the height of the highest plant in an infected tree. There is some evidence that long distance spread of dwarf mistletoe is occassionaly vectored by birds and animals.

Vertical spread within tree crowns of most dwarf mistletoes is limited to less than one foot per year because of foliage density. Because of the thin crowns of gray pine, however, the vertical rate of spread has been

measured as being greater than 2 feet per year. This rate of spread equalled or exceeded the rate of height growth of infected trees.

Dwarf mistletoes are easy to identify because they are generally exposed to view within a tree's crown. Signs of infection include the yellow-green to orange mistletoe plants, basal cups on a branch or stem where the plants were attached and detached plants on the ground beneath an infected tree. Symptoms include spindle-shaped branch swellings, witches' brooms in the lower crown, and bole swellings.

Cytospora canker of true firs

Cytospora abietis is a damaging, canker-inducing fungus that commonly occurs on true firs throughout their natural range in California, central and eastern Oregon, and frequently on firs and Douglas-fir elsewhere in the western United States. A weak parasite, it attacks only trees that have been debilitated by other disease-causing agents, drought, fire, insects, and human activities.

One of the important factors that predispose firs to infection by *C. abietis* is dwarf mistletoe. Practically all fir stands in California and Oregon infested with dwarf mistletoe are infested with this fungus. *C. abietis* more commonly infects branches invaded by dwarf mistletoe and in some stands nearly a fourth of all branches bearing mistletoe are infected. Thus, in mistletoe-infected fir stands, considerable branch killing occurs each year as a result of this canker organism and occasionally trees are killed. Because this fungus sometimes reaches damaging proportions, *C. abietis* can constitute a threat to the management of true firs.

White pine blister rust

White pine blister rust is caused by *Cronartium ribicola* an obligate parasite that attacks 5-needled pines and several species of *Ribes* spp. The fungus needs the two alternate hosts to survive, spending part of its life on 5-needled pines and the other on *Ribes* spp. The disease occurs throughout the range of sugar pine to the southern Sierra Nevada, but has not been reported further south. Infection of pines results in cankers on branches and main stems, branch mortality, top kill, and tree mortality.

Spores (aeciospores) produced by the fungus in the spring on pine bole or branch cankers are wind-disseminated to *Ribes* spp. where they infect the leaves. Spores (urediospores) produced in orange pustules on the underside of the leaves reinfect other *Ribes* spp. throughout the summer, resulting in an intensification of the rust. A telial spore stage forms on *Ribes* spp. leaves in the fall. Teliospores germinate in place to produce spores (sporida) which are wind-disseminated to pines and infect current year needles. Following infection, the fungus grows from the needle into the branch and forms a canker. After 2 or 3 years, spores are produced on the cankers and are spread to *Ribes* spp. to continue the cycle. Although blister rust may spread hundreds of miles from pines to *Ribes* spp., its spread from *Ribes* spp. back to pines is usually limited to a few hundred feet.

Branch cankers continue to enlarge as the fungus invades additional tissues and moves toward the bole. Branch cankers within 24 inches of the bole will eventually form bole cankers. Bole cankers result in girdling and death of the tree above the canker. Cankers that have margins more than 24 inches from the main bole are unlikely to reach the bole and only branch flagging will result.